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EVALUATION OF HIGH-VOLTAGE, HIGH-POWER, SOLID-STATE
REMOTE POWER CONTROLLERS FOR AMPS

| | |
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ABSTRACT

The Electrical Power Branch at Marshall Space Flight Center is developing a Power System Development Facility where various power circuit breadboards are under development and evaluation. This project relates to the evaluation of a particular remote power controller(RPC) energizing high power loads. The Power System Development Facility equipment permits the thorough testing and evaluation of high-voltage, high-power, solid-state remote power controllers. The purpose of this work is to evaluate a Type E, 30 Ampere, 200 V DC remote power controller.

Three phases of the RPC evaluation are presented. The RPC is evaluated within a low-voltage, low-power circuit to check its operational capability. The RPC is then evaluated while performing switch/circuit breaker functions within a 200 V DC, 30 Ampere power circuit. The final effort of the project relates to the recommended procedures for installing these RPC's into the existing Autonomously Managed Power System(AMPS) breadboard/test facility at MSFC.

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INTRODUCTION

'Space Power Automation' is becoming a more aggressively pursued research area. A considerable number of publications have already been published, and the conference proceedings are including more publications on the subject each year. Along with the topic of 'Space Power Automation', the phrase, 'Autonomously Managed Power System' is also being used quite frequently to describe the area of space power research and development.

The Electrical Power Branch at Marshall Space Flight Center is developing a Power System Development Facility where various electrical power systems breadboards are under development and evaluation. These include a modular 5KW, 440 V, 20 KHZ Breadboard, a 24 KW, 200 V DC Autonomously Managed Power System (AMPS) breadboard/test facility, a 25 KW space station Core Module Power Management and Distribution (CM/PMAD) system breadboard, and computer/AI workstations.

A specific item to be evaluated in the Power System Development Facility is the Remote Power Controller (RPC). The high-voltage, high power, solid-state remote power controller for aerospace applications will be incorporated into the power circuit breadboards for testing and evaluation. The purpose of this paper is to provide background information on the power breadboard facility, provide general information regarding remote power controllers, and to present the results of an evaluation of a Type E, 200 V DC, 30 AMP, remote power controller. A recommended procedure for incorporating these RPC's into the AMPS Breadboard in the existing Power System Development Facility is also included.

OBJECTIVES

The objectives of this work included the following:

- I. Prepare the RPC for non-destructive evaluation by:
 - A. Securing the base of the RPC to an appropriate heat sink.
 - B. Installing protective zener diodes at the power FET's position within the RPC.
- II. Design and construction of the RPC operational test board to permit:
 - A. Sending "ON" commands to the RPC.
 - B. Sending "OFF" commands to the RPC.
 - C. Providing annunciation lamps to indicate "ON" and "TRIPPED" conditions of the RPC.
 - D. Provide terminals for receiving telemetered information from the RPC.
- III. Plan and conduct RPC high voltage and low voltage tests to measure:
 - A. Effect of reducing RPC control voltage.
 - B. Characteristics of telemetered signals from the RPC.
 - C. Response of RPC to control commands.
 - D. Voltage across and current through the RPC during:
 1. Normal "TURN ON".
 2. Normal "TURN OFF".
 3. Turn on into overcurrent type loads and short circuits
 - E. Times associated with fast and slow overcurrent trips.
 - F. Ability of RPC to produce "SOFT TURN ONS".
 - G. Voltage drop across the switch during normal operation.
- IV. To present a recommended procedure for installing RPC's into the existing power development facility.

THE POWER SYSTEMS DEVELOPMENT FACILITY

Under the direction of the Electrical Power Branch of the Electrical Division of the Information and Electronic Systems Laboratory the Power System Development Facility has been established and continues to be developed.(Fig.1) The author's NASA/ASEE 1986 report provides a general description of the facility and describes the rationale associated with the gradual development of the facility(Ref.1). The most important and valuable quality of the facility is its flexibility and adaptability wherein a wide variety of future power circuit concepts and breadboards can be tested and evaluated(Ref.2 through 5).

The facility is equipped with a wide variety of computers, printers, and software development workstations for producing the necessary test software associated with all the power system breadboards(Ref.1). The host computers, equipment-embedded computers, and artificial intelligence computers, associated with AMPS, are connected via an ethernet(Ref.1 through 5).

The Autonomously Managed Power System:

The Autonomously Managed Power System (AMPS) is a proof-of-concept breadboard of an end-to-end high voltage, high power electrical power system. It is essentially comprised of photovoltaic electrical energy collection simulators, battery energy storage facilities, and a large load center.(Fig.2) The breadboard has a 75 KW solar array simulator for the power generation source. The energy storage sub-system consists of a 168 cell nickel-cadmium battery with 189 ampere hour capacity. The load facility within AMPS consists of 21 KW resistive loads which can be configured in almost any arrangement in units as small as 0.33 KW, and fed from any of the available busses. A 3 KW load is also available as a pulsed load to produce power circuit noise simulation at frequencies between 30 HZ and 20 KHZ.(Ref.1 through 5).

MSFC POWER SYSTEMS DEVELOPMENT FACILITY

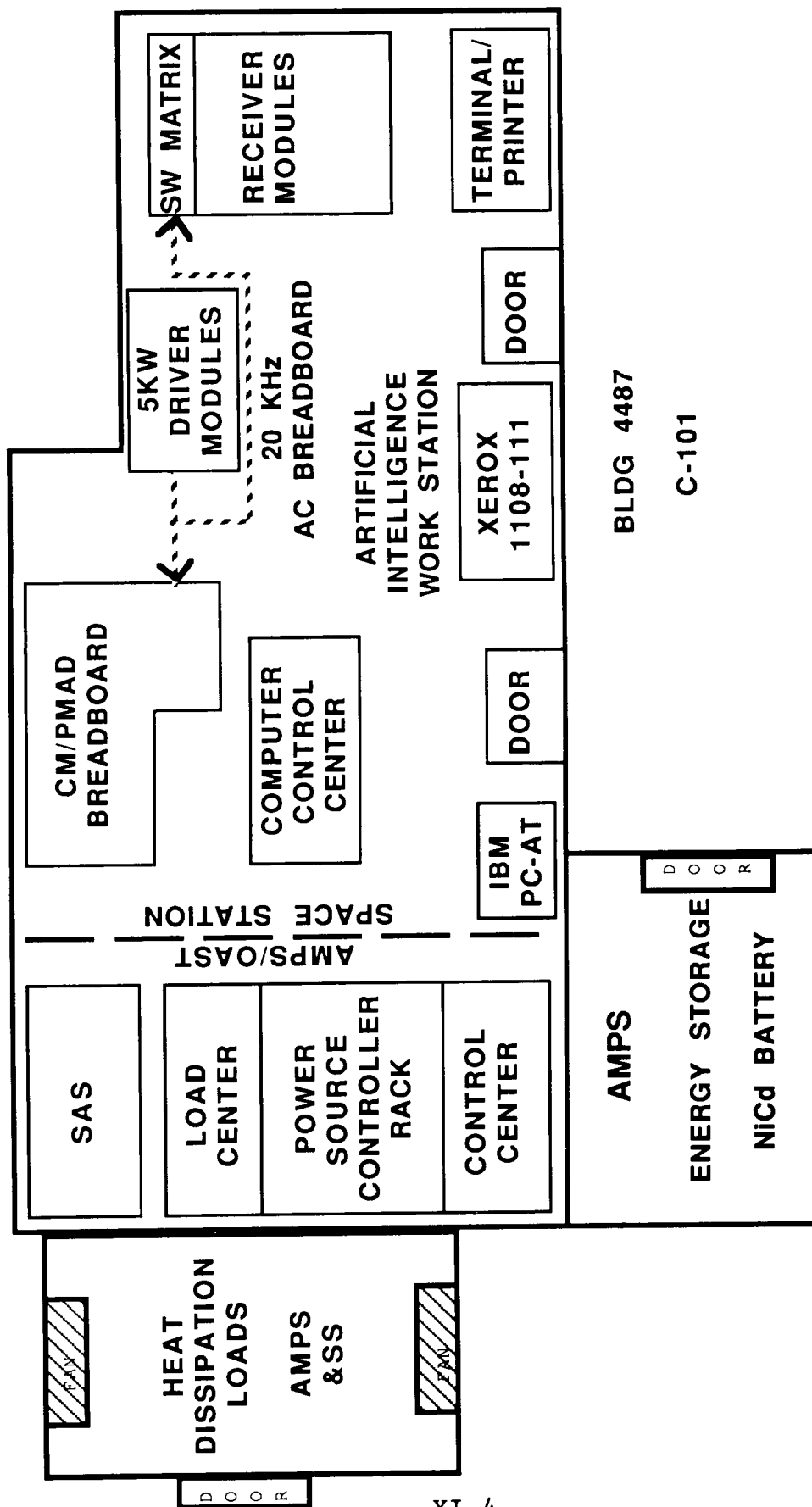


Figure 1

AUTONOMOUSLY MANAGED POWER SYSTEM

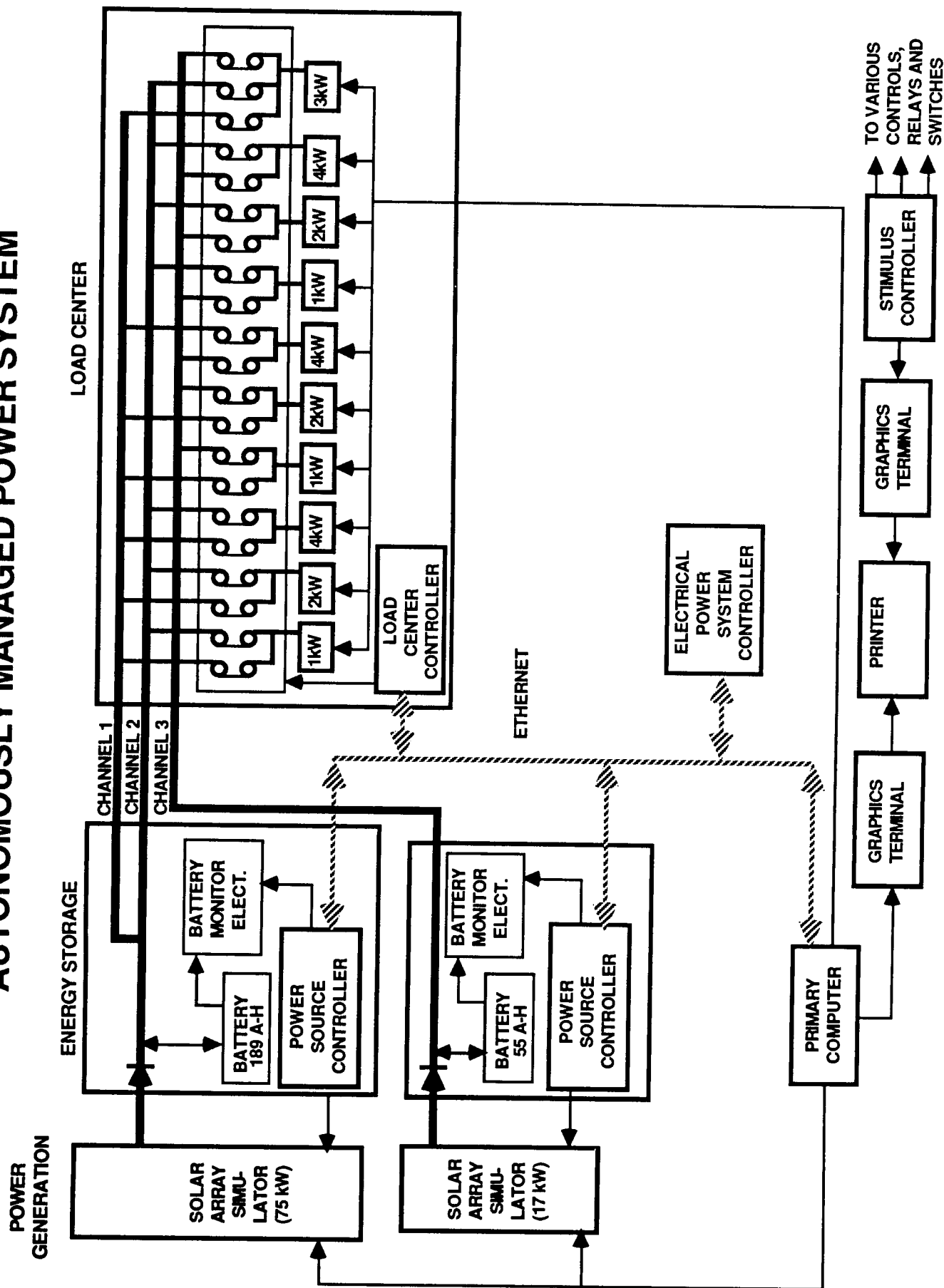


Figure 2

REMOTE POWER CONTROLLERS

In space power automation, remote power controller(RPC) generally refers to a solid-state, remote controlled device used to energize a high power load by using a low power, low voltage signal to produce switching which connects/disconnects the load with its supply voltage. For spacecraft electrical power systems, the solid-state RPC is greatly preferred over the ordinary electromechanical relay for accomplishing power switching and circuit breaking operations.

Background:

RPC's have been in development for many years, and the desirable characteristics are well established. The general RPC specifications which are accepted today are given in Table 1.(Ref.14). Although the particular performance specifications vary greatly for the various types of RPC's, the general features of the RPC appear to be the most interesting. For example, a "good" RPC should provide "soft" turn on and turn off characteristics as applied to the energizing and current change within a particular load. This is often referred to as causing the current to "ramp" to and from its maximum value for the load. Also, the "good" RPC should have overcurrent protection to protect itself and its load. Generally the overcurrent protection features provide for inverse-time type of overcurrent tripping associated with currents approaching 100-200% load currents. An instantaneous tripping feature is also included, which provides for microsecond types of trips associated with pre-set extremely high currents such as 300% overload currents.

RPC Design Features and Requirements:

A rugged RPC is expected to protect itself and its load when the supply voltage for the load is instantly shorted or is turned on into a short.

The need for the continued development of RPC's capable of providing power switching/circuit breaker action becomes obvious when one reviews the recent literature concerning the speculative values for the power requirements for future spacecraft.(Ref 6-8). During the past few years considerable effort has been made in developing RPC's capable of providing switch/circuit breaker action in higher voltage DC systems(Ref. 9-13). The development goal of providing RPC's capable of switching high power at high voltage in times of a few microseconds, while providing "current-ramping", "soft turn-on", thermal type overcurrent protection is not easily attained.

TABLE I.—GENERAL RPC SPECIFICATIONS

| | |
|---|--|
| Rated operating voltage, V dc | 150 to 1200 |
| Rated output current, A dc | ≤ 100 |
| Control power source, V dc | 28 ± 7 |
| Low control power protection | Shutdown for < 21 V |
| Control voltage | TTL compatible |
| On-and-off control signals | Logic "O" (low) |
| Overload trip indication | TTL signal—high after trip |
| Overload reset | Resets on "off" command |
| Turnon delay, ms | 100 max. |
| Rise and fall times, μs | 100 desired |
| Voltage drop at rated load, V dc | 2.0 max. |
| Power dissipation off, W | 0.5 max. |
| Efficiency at 20 to 100 percent of rated load current, percent | ≥ 99 (including control power) |
| Overload tripout | Proportional to I^2t |
| Fault response time, μs | 3 |
| Fault trip level | 2 to 3 per unit |
| Operating temperature, °C | – 50 to 75 |
| RPC protection | RPC must be self-protecting under all conditions including maximum fault current |

Table 1 (Reference 14)

RPC CHARACTERISTICS

| | RPC model | | | |
|-----------------------------------|-----------|----------------------|--------|--------|
| | A | E | F | G |
| Operating voltage, V | – 750 | 300 | 150 | 800 |
| Full load current, A | 0.04 | 35 | 100 | 10 |
| Switching time (on/off), μs | 5 | 50 | 250 | 100 |
| Fault turnoff time, μs | 120 | 2 | 3 | 3 |
| Switch-on drop at full load, V | 0.25 | 1.7 | 2.0 | 3.8 |
| Efficiency, percent | 99.9 | 99.4 | 98.7 | 99.5 |
| Device | MTP1N100 | IRF350 or VNM005A | IRF250 | BUZ54A |

Table 2 (Reference 14)

Evaluation of a Type E, 200 V DC, 30 A RPC:

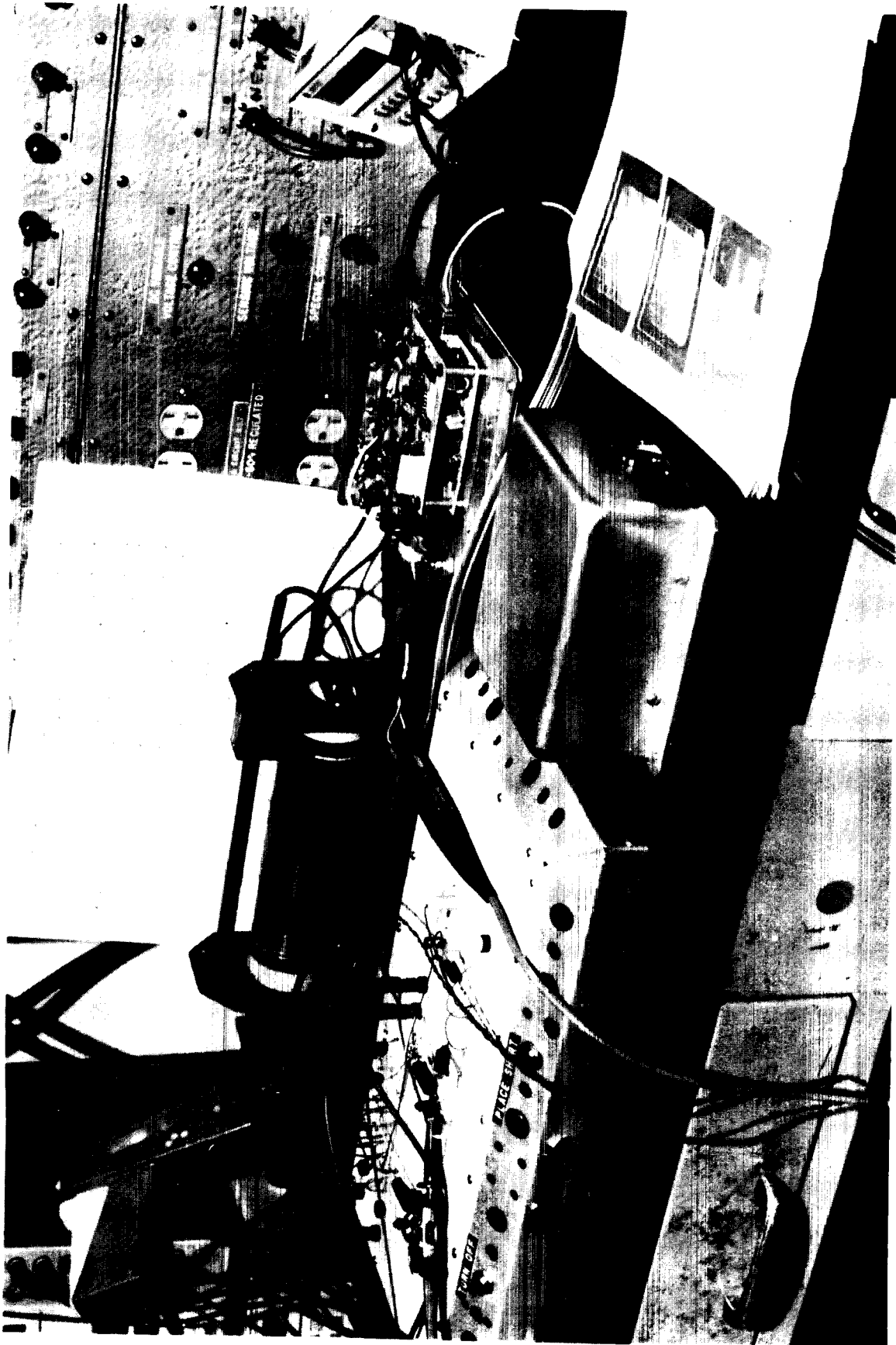
The particular RPC being evaluated is referred to as a Type E RPC. The general characteristics of the Type E are given in Table 2. The RPC was equipped with a 9-pin connector for attaching a control cable. The control cable configuration is given in Table 3. A control circuit for the RPC test was designed to provide commands to the RPC and to receive telemetered information and status signals during operation of the test. The essential features of the test board circuit are given in Table 3. The test set-up is shown in figure 3, with the test circuit arrangement in the left foreground, and the test RPC shown on the right.

The test circuit is shown in figure 4. The general nature of the feedback from the RPC via the control cable is given in Table 3. The telemetered information provided through the control cable provides an analog voltage indicative of load current through the switch and the voltage appearing across the switch. The oscilloscope photos reflect the fact that the switch recovers the load supply voltage when the RPC has opened the switch. The voltage measured across the switch becomes the voltage drop associated with the RPC switch when the load is energized and the supply voltage nearly all appears across the load. The general performance of the test RPC is shown with typical oscilloscope photos in figures 1-10.

The photos in figures 5 and 6 show the soft current rise through the switch and the passing of the supply voltage from the switch to the load during normal turn-on and turn off. Figure 7 is an oscilloscope photo showing the switch current and voltage transients during turn on into an 80 amp load (267% overload). This overload would produce a thermal, or timed, trip not shown on this trace. Figure 8 simply shows the recorded time required for a thermal trip to occur as associated with a particular overload. Figures 9 and 10 are included to show switch response to sudden overloads or shorts. In the event of a sudden overload or short which produces a steady state current of over 90 amps, the RPC ramps the current to 90 amps and performs its fastest turn-off, which is accomplished within one or two micro-seconds. Table 4 is included to show the inverse-time characteristics of the slow overcurrent trip feature of the RPC.

The only problem encountered during the evaluation procedures, was associated with the failure of an opto-isolation circuit related to the "on" feedback signal of the RPC control circuitry. During the low voltage test phase, a short was placed across the load position, causing the RPC to trip, and produce a trip indication on the control board. The failure of the opto-isolation circuit caused the RPC to also produce an "on" indication when

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RPC Test Set-Up

Figure 3

POWER CIRCUIT FOR RPC EVALUATION

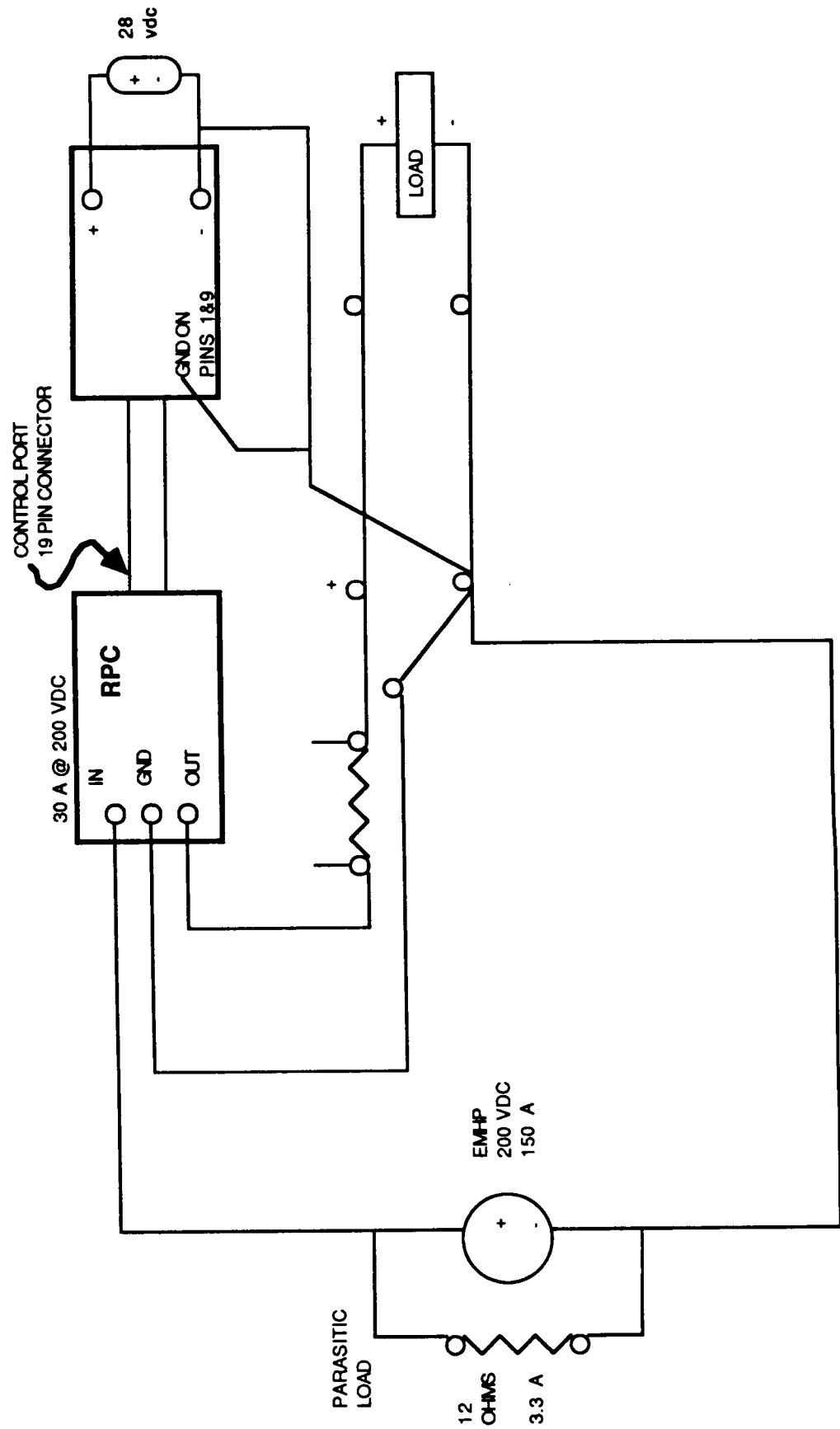


Figure 4

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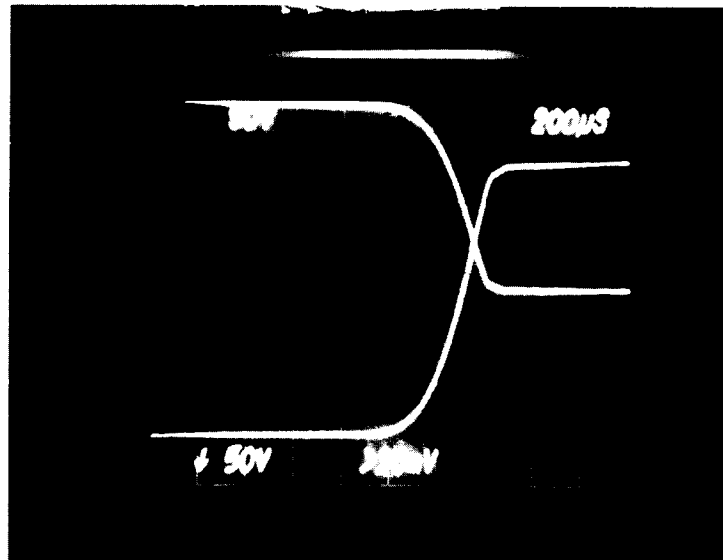


Figure 5 - Normal Turn On
(5 AMP/DIV, 50 V/DIV)

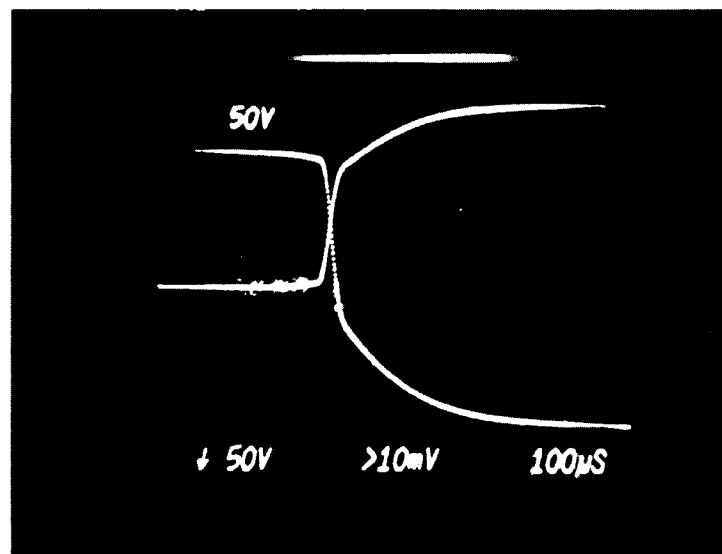


Figure 6 - Normal Turn Off
(5 AMP/DIV, 50 V/DIV)

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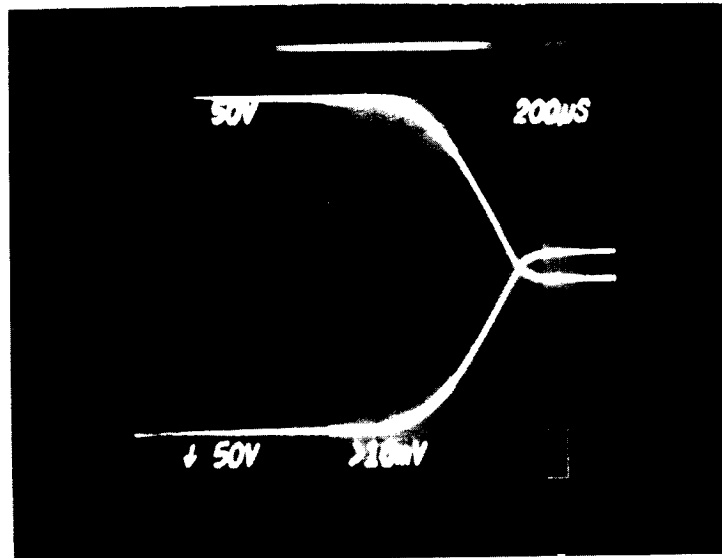


Figure 7 - Normal Turn On into 80 AMP
Load. (20 AMP/DIV, 50 V/DIV)

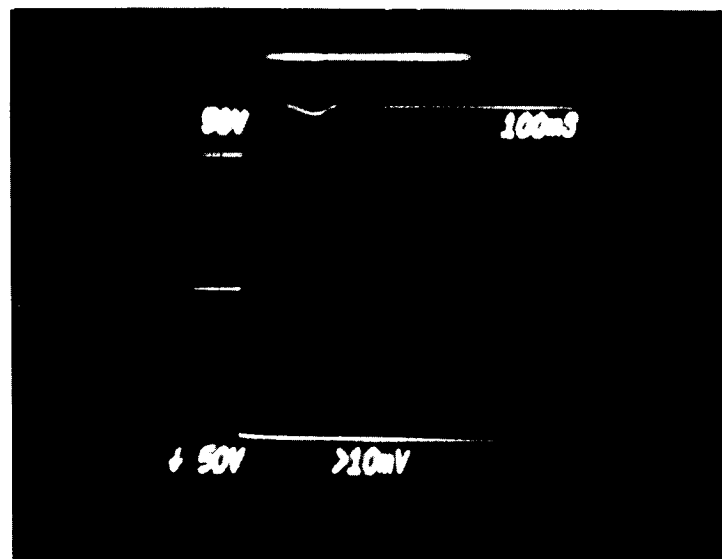


Figure 8 - Slow Overcurrent Trip
(10 AMP/DIV, 50 V/DIV), 2.5 seconds
to trip at 60 AMPS

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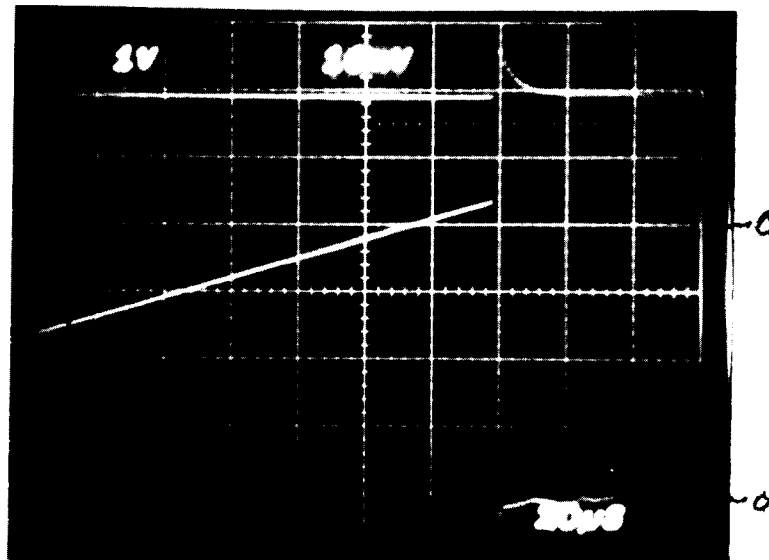


Figure 9 - Turn On into Short
(20 AMP/DIV, 100 V/DIV)
(Reference 14)

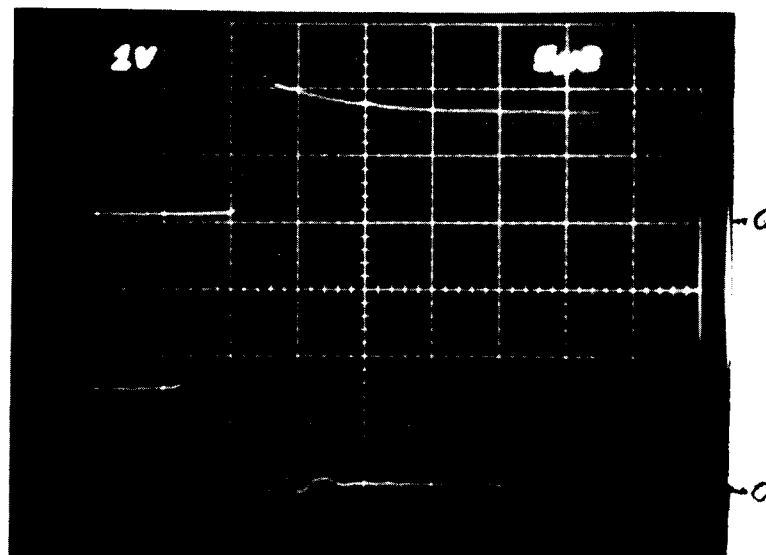


Figure 10 - Short from Full Load
(20 AMP/DIV, 100 V/DIV)
(Reference 14)

SLOW OVERCURRENT TRIP CHARACTERISTICS

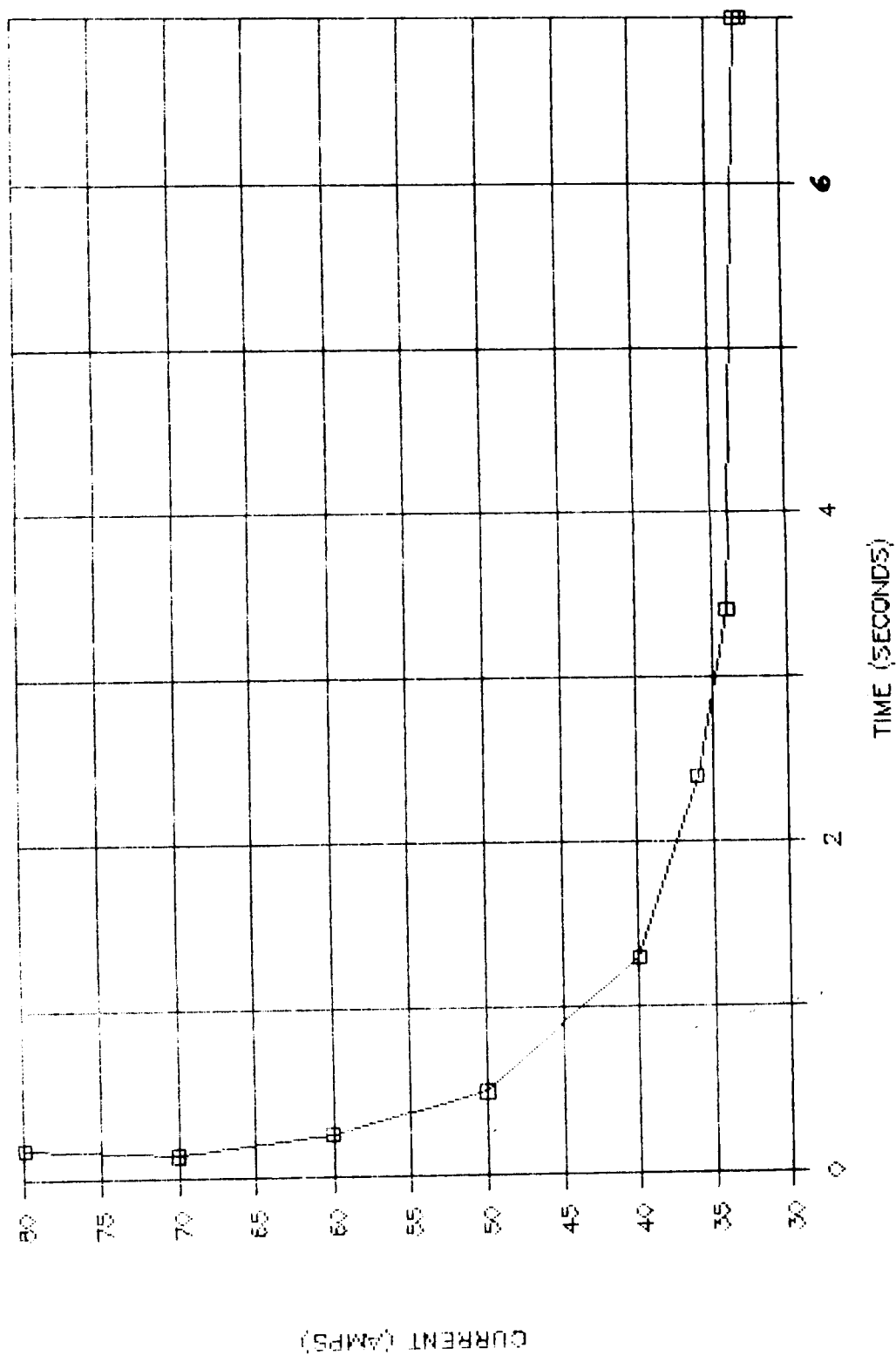


Figure 11

CONTROL CABLE CONFIGURATION

| CONDUCTOR # | FUNCTION |
|-------------|---|
| 1. | PROVIDE GROUND. THIS GROUND IS BOTH THE LOW POTENTIAL OF THE CONTROL VOLTAGE AND THE MAIN SUPPLY VOLTAGE FOR ENERGIZING THE LOAD. |
| 2. | +28 VDC. EXTERNALLY PROVIDED DC VOLTAGE FOR OPERATION OF CONTROL CIRCUITS IN RPC. |
| 3. | "COMMAND ON". MOMENTARY GROUND COMMANDS THE RPC TO TURN THE SWITCH ON AND APPLY MAIN SUPPLY VOLTAGE TO LOAD. |
| 4. | "TRIPPED OFF". LOW VOLTAGE FEEDBACK FROM THE RPC INDICATES THAT THE RPC INTERRUPTED POWER TO THE MAIN LOAD DUE TO OVERCURRENT OR FAULT IDENTIFICATION. |
| 5. | "COMMAND OFF". MOMENTARY GROUND COMMANDS THE RPC TO TURN THE SWITCH OFF AND DE-ENERGIZE THE LOAD. |
| 6. | FEEDBACK FROM RPC TO INDICATE LOAD CURRENT OR CURRENT THROUGH THE SWITCH. (ANALOG VOLTAGE). |
| 7. | "ON". LOW VOLTAGE FEEDBACK FROM THE RPC INDICATES THAT THE RPC IS ON AND CURRENT IS BEING CONDUCTED THROUGH THE LOAD. |
| 8. | FEEDBACK FROM RPC TO INDICATE VOLTAGE APPLIED TO LOAD. (MEANING VOLTAGE IS EXTENDED THROUGH THE SWITCH TOWARD LOAD). ANALOG VOLTAGE PROPORTIONAL TO ACTUAL VOLTAGE. |
| 9. | COMMON GROUND. (REDUNDANT CONNECTION) |

Table 3

SLOW OVERCURRENT TRIP TIMES

| CURRENT (AMPS) | TIME (SECONDS) |
|-------------------|-------------------|
| 32.6 | 7 |
| 33 | 7 |
| 34 | 3.4 |
| 36 | 2.4 |
| 40 | 1.3 |
| 50 | 0.5 |
| 60 | 0.25 |
| 70 | 0.13 |
| 80 | 0.17 |

Table 4

the unit was actually "off". After the opto-isolation circuit was repaired, the problem was repeated three times. At that point, voltage surge protection was installed at the installation site of the opto-coupler. Suppression capacitors and zener diodes were installed as the protection devices. No further failures were produced.

INSTALLATION OF RPC'S IN AMPS

The existing AMPS breadboard utilizes approximately 20 electromechanical relays to configure a desired load and perform load balancing operations. Considerable engineering design changes would be required to remove these RPC simulators and replace them with solid state RPC's. It seems appropriate to incorporate a few RPC's into AMPS as soon as possible, so that the existing facility breadboard may begin a more realistic test of spacecraft components.

It appears that two 200 V DC, 30 A RPC's could appropriately be installed in AMPS with a minimum number of hardware and computer software changes. The positive cable at the battery and the positive cable at the Solar Array Simulator output could be interrupted and routed through a Type E RPC. The 28 V DC supply for the RPC control circuits is not available in AMPS. Some signal-conditioning interfacing would also be needed to provide computer control of the installed RPC's.

The two RPC's would provide redundant switches associated with the battery and the Solar Array Simulator output. However, the "soft turn-on" and intelligent overcurrent protection provided by the RPC's would permit greater latitude with added fault-interruption capability during regular AMPS experiments.

A second phase related to the incorporation of RPC's into AMPS would be a project to replace the electromechanical relays(RPC simulators) with RPC's. The original design of AMPS should accommodate this project. It is expected that most of the effort required on this project would be related to software changes to accommodate the additional control and feedback associated with the RPC's. For those who may be involved in the relay/RPC exchange, a few observations are offered. The existing 120 V AC relay coil supply voltage will need to be replaced by a 28 V DC supply to energize the RPC control circuitry. The contacts presently used to turn on the relay coils, will need to be replaced by momentary ground switches to turn the RPC on and off.

Reasonably good detail of the existing circuitry is available on print no. D771232, sheet 2 of 3. and the SOTCHER(sub-contractor) print no. 1237B. A good example for review is the RPC Simulator

no. 1, related to the low, medium, and high switching of one of the 4 KW loads. Present logic uses 12 V DC signals to energize 12 V relay coils, and the contacts of these to energize 120 V AC relays to accomplish the necessary switching. One should not forget that the RPC's also provide analog voltage feedback related to current through the switch and voltage across the switch, in addition to "on" and "tripped" annunciation signals. During the relay/RPC exchange these "extras" should produce no problem, even if they are not used by AMPS after the exchange. The existing relays are three-pole, single throw, and are energized with 120 V AC, 60 HZ; and of course are noisy when operated. Each of the existing relays occupies only about 3 inches by 5 inches of horizontal space in the AMPS cabinets, with six per horizontal rack. The "quiet" RPC's will need much more space; but there is ample space in unoccupied racks below the existing relays.

Eighteen RPC's will be needed to replace the relays that are presently used in configuring loads. The highest current that will be switched by any of these RPC's will be that of two thirds of the current related to one of the 4 KW loads (13.33 Amps). If eighteen or more RPC's can be obtained for the project, it would seem appropriate to replace the relays used in load configuring. However, if only a few RPC's will be available, I recommend the installation of them in more obvious, more critical sites; such as in-line breakers in the Solar Array Simulator output or the battery output.

CONCLUSIONS AND RECOMMENDATIONS

The power System Development Facility of the Electrical Power Branch is rapidly becoming a very complete and sophisticated power system breadboard development laboratory. The AMPS breadboard offered an excellent environment and test site for the Type E RPC's evaluated.

The Type E RPC performed well within its acceptable specifications. Its performance during the more stressful tests demonstrated the ruggedness required of a high-power switch/breaker for spacecraft applications.

The Type E RPC should offer considerable enhancement to the AMPS breadboard. The installation will necessarily require some software changes; but the flexibility of the breadboard will allow a relatively simple adaption. The installation of the RPC's in the AMPS breadboard will permit logging of additional evaluation and characterization time on the RPC's themselves, add additional "smart" overcurrent protection to the breadboard, and demonstrate the flexibility of the MSFC Power Systems Development Facility.

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